Coupled Thermocline – Deep Ocean Processes in Baroclinic Fronts and Eddies: Toward Improving Model Initialization and Data Assimilation

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LONG-TERM GOAL

Our long-term goal is to achieve a correct understanding of the physical processes at the continental margin interface, including feedbacks between the coastal and open ocean, and to investigate the ability of numerical models to simulate physical processes over continental slope regions.

SCIENTIFIC OBJECTIVES

The specific scientific objectives of this project are focused on studying the dynamical coupling between meandering baroclinic jets and cut off eddies with the deep flow over variable topography. Emphasis is placed on improving our understanding of the life cycle of energetic flow perturbations excited by meandering of baroclinic jets and/or warm-core rings approaching the shelf break from the open ocean. The gained knowledge would allow us to develop new model initialization and data assimilation techniques.

APPROACH

Our approach combines theoretical investigation with advanced numerical modeling to gain understanding and efficient representation of the most important physical processes in the littoral zone. In collaboration with Watts' (URI) project we use analytical and numerical models for analyses of the SYNOP data set.

WORK COMPLETED

We have investigated the effects of bathymetry on the growth of instabilities and zonal flow modification of a Gulf Stream–type jet. Initial jet was prescribed as a potential vorticity (PV) front in the upper thermocline overlying intermediate layers with weak PV gradients and quiescent bottom layer over either constant or variable bottom slopes. The numerical experiments were conducted with two different models: the Intermediate Equation Model (Sutyrin, 1994) and the primitive equation Princeton Ocean Model.

We have developed and verified an analytical model of the mean flow structure created by the jet meandering, which is based on homogenization of PV in the lower layer. A scaling model for the meander amplitudes and intensity of deep eddies was suggested that is based on two parameters: the bottom slope and mean ocean depth.

We have studied the interaction between an eddy and a Gulf Stream-type jet, focusing on the behavior of an eddy with a compact PV core in a vertically sheared baroclinic current.

RESULTS

a. ***Zonal flow modification over a sloping bottom***

Our numerical experiments indicate that the main effect of the energetic deep eddies generated by a baroclinically unstable jet over a cross-stream sloping bottom is the homogenization of the lower layer PV. The resulting PV homogenization underneath the jet eliminates the source for the baroclinic instability and provides the main equilibration mechanism for the deep eddies and meanders over a topographic slope. The equilibrated deep eddies form a nearly zonal flow behind the meander packet, while the upper baroclinic structure remains almost unaffected by this process (see the lower panel in Fig. 2). The structure of the zonal flow can be predicted by an analytic model that includes three parameters, e.g., mean modified PV value behind the wave packet and the widths of northern and southern PV modification zones (Fig. 1). The deep flow resulting from PV modification during the jet meandering over the continental slope is consistent with observed circulation in the Gulf Stream system. These results also suggest that the deep circulation should be taken into account in adequate initialization and data assimilation methods

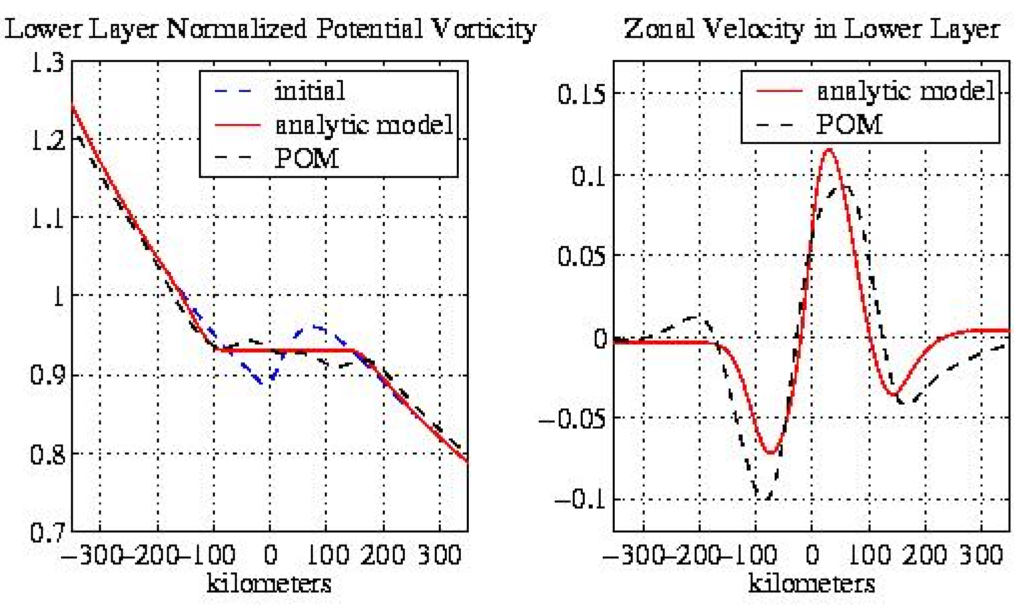

Fig. 1 Left panel: zonally averaged lower layer PV behind the meander packet: initially (dashed blue line) and time t= 40 days (dash black line) compared to the analytic model (solid red line) for a slope 0.003. Right panel: corresponding meridional profile of the modified zonal flow (m/s) in the lower layer at time t = 40 days (black dashed line) and the analytic model prediction (solid red line).

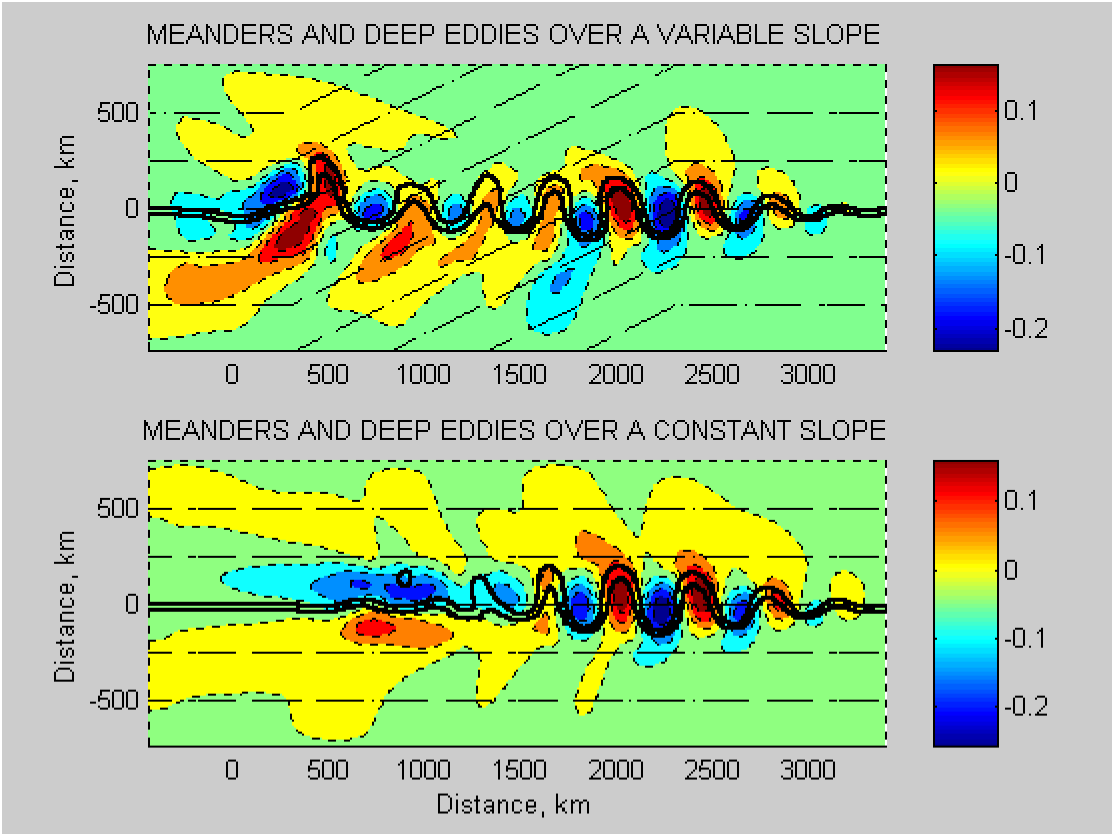

Fig.2 The structure of the baroclinic front and deep flow over a variable bottom slope with increasing downstream mean ocean depth from 2 km to 4 km (upper panel) and over a constant bottom slope with a mean ocean depth 4 km (lower panel) at day 60 simulated by the 5-layer Intermediate Equation Model. The temperature front at 250 m is shown by the bold contours. The deep pressure field (in decibars) is shown by color: cyclones (blue) and anticyclones (red). Bathymetry is shown by dashed contours with CI=500 m.

b. ***Effects of variable bottom slope on meanders and deep eddies in a Gulf Stream-type jet***.

For a constant bottom slope the meander amplitudes decrease when the slope or/and mean ocean depth increase. The maximum vorticity of the associated deep eddies is determined by a combination of two factors:

1) stretching of the vortex tubes in the lower layer due to changes in the thermocline depth associated with the meander propagation;

2) nonlinear advection of PV anomalies by the deep eddies.

This maximum vorticity can be estimated analytically from the initial PV distribution and thermocline depths at the northern and southern sides of the jet. It decreases with increasing the mean ocean depth or/and the bottom slope, in good agreement with the numerical simulations.

For a variable slope with increasing mean ocean depth downstream, the frontal part of the meander packet evolves in a similar way as for the constant slope. However, behind the packet, the meanders do not decay and deep eddies are not able to form a mean zonal flow because of the topographic Rossby wave (TRW) radiation across the jet along the bathymetry contours (compare the upper and lower panels of Fig. 2).

c. *Interaction of a baroclinic vortex and a vertically sheared current*

Three major effects are found to contribute into the interaction of a vertically sheared flow and a localized vortex: advection by the mean current, the beta-gyres developed due to the background PV gradient, and vertical tilting of the vortex core. Using an azimuthal mode decomposition we concluded that the trajectories of oceanic eddies (cyclones and anticyclones) in a vertically sheared current are modified due to mainly two factors: (a) rotational advection of the mean current PV, and (b) vertical coupling of tilted parts of the vortex core. We have found that the first effect compensates most of the advection by the mean current due to homogenization of PV inside the vortex core. Thus, the net advective effect of a vertically sheared current on a coherent vortex is strongly reduced: the vortex is advected mainly by the planetary beta-gyres and the depth-averaged current.

IMPACT/APPLICATION

The means by which we have analyzed the evolution of baroclinic vortices and meanders over topography are novel and useful for future investigations. Mechanisms of zonal flow modification due to nonlinear equilibration of the Gulf Stream meanders and deep eddies over a sloping bottom and effects of variable bottom slope have not been explained previously. This has implications for our understanding of coupling, horizontal and vertical, of flow over the topography of the continental margin.

TRANSITIONS

Our approach to the potential vorticity gradient representation has been successfully used in other ONR-funded studies of the Gulf Stream structure (Watts, URI) and initialization of the Princeton Ocean Model for coupled hurricane - ocean forecasts (Ginis, URI). The developed new data assimilation scheme for Gulf Stream initialization is presently being implemented at the National Centers for Environmental Prediction (Ginis, URI).

RELATED PROJECTS

Dr. Randy Watts (URI) uses the PV-gradient model developed in this project for analysis of the observed velocity and density structures during the SYNOP field experiment.

Drs. Isaac Ginis and Lew Rothstein (URI) use the PV initialization approach for modeling hurricane - ocean interaction.

Dr. Isaac Ginis (URI) uses the PV initialization technique in the NOPP project: Coastal Marine Demonstration of Forecast Information to Mariners for the U.S. East Coast.

Drs. Yves Morel (SHOM, France) and Georgi Sutyrin (URI) use asymptotic methods developed in this project to investigate vortex interaction with a vertically sheared surrounding flow.

Drs. Gregory Reznik (IORAS, Russia) and Georgi Sutyrin (URI) analyze mutual effects of topography and baroclinicity on long-lived vortices to improve our understanding of vertical coupling over a sloping bottom.

REFERENCES

Sutyrin, G.G., 1994: Long-lived planetary vortices and their evolution: conservative intermediate geostrophic model. *Chaos*, **4**, 203-212.

PUBLICATIONS

Frolov, S.A., Sutyrin, G.G., and I. Ginis, 1999: Effects of deep flow on the stability of the Gulf Stream system. EOS Transactions Americ. Geophys. Union, **80**, OS42P-3.

Logoutov, O.G., Sutyrin, G.G., and D.R. Watts, 2000: Potential vorticity structure across the Gulf Stream: Observations and a PV-gradient model. *J. Phys Oceanogr*. In press.

Logoutov, O.G., Sutyrin, G.G., and D.R. Watts, 1999: A PV-gradient model of the Gulf Stream, estimated from observations. EOS Transactions Americ. Geophys, Union **80**, OS32A-6.

Sutyrin, G.G. 2000: Balanced models of baroclinic jets and eddies. Geophys. Res. Abs. **2**., 25th General Assembly of EGS, Nice, France.

Sutyrin, G.G., I. Ginis, and S.A. Frolov, 2000: Equilibration of the Gulf Stream meanders and deep eddies over a sloping bottom. *J. Phys. Oceanogr.* In press.

Sutyrin, G.G., I. Ginis, and S.A. Frolov, 1999: Coupling of Gulf Stream meanders and deep eddies over a sloping bottom. EOS Transactions Americ. Geophys. Union, **80**, OS32A-26.

Sutyrin, G.G., I. Ginis, and S.A. Frolov, 2000: Nonlinear equilibration of a baroclinically unstable jet over topographic slope, Proceedings of IUTAM Symposium "*Advances in Mathematical Modelling of Atmosphere and Ocean Dynamics*". Submitted.

Vandermeirsh, F.,Y. Morel, and G.G. Sutyrin, 2000: The net advective effect of a vertically sheared current on a coherent vortex. *J. Phys. Oceanogr.* Submitted.

Vandermeirsh, F., Y. Morel, and G.G. Sutyrin, 2000: Interaction of a vortex with a large scale current. Geophys. Res. Abs. **2**. 25th General Assembly of EGS, Nice, France.